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(6) FIRE CASUALTIES AND THEIR RELATION TO FIRE COMPANY RESPONSE DISTANCE AND DEMOGRAPHIC FACTORS

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PREFACE

This study was conducted for the New York City Fire Department by The New York City-Rand Institute as part of its work on the analysis of fire fatalities.

SUMMARY

Fatalities and injuries per structural fire in New York City have been compared by time of day, season, year, construction, region of the City, floor of origin, and occupancy. The relationship between response distance and fire casualties has also been studied. It has been found that the number of casualties per structural fire has not been increasing over time. There are, however, significant time-of-day and time-of-year effects on risk of life that should be taken into account in providing fire-protection services. Other casualty indices provided inconclusive results since certain categories, such as casualties occurring in tenements, could reflect social as well as building-construction problems.

A statistically significant, but very small, relationship was found between response distance and fire casualties. The effect of response distance on casualty risk is so overwhelmed by other factors that risk of life cannot be used as the primary criterion in developing mathematical fire-resource allocation models.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

In 1972, there were 279 deaths and 1986 civilian injuries resulting from fires in New York City. A basic responsibility of the Fire Department is to keep the number of fire casualties at a minimum. In fulfilling this responsibility, the Department deploys its equipment so that it can make a speedy response when it is informed of a fire. To do this effectively, however, two questions need to be answered: (1) What is the relationship between fire-company response distance and the risk of a casualty? (2) How is the risk of a casualty affected by demographic and temporal factors?

If the risk of a fire casualty were evenly distributed throughout the City, the task of deploying fire-fighting resources to minimize this risk would be relatively simple; each area of the City should be given a level of service equal to that of any other area. In actuality, however, the task of deployment is not so easy, because the chance of a fire death or injury varies greatly from one region of the City to another.

Part of the risk of a fire casualty is reflected in the level of fire incidence of a given area. These levels are not sufficient, however, to determine the threat to safety because fires vary greatly in seriousness and because, within a given region, fire hazard may vary from occupancy to occupancy. Furthermore, an occupancy that presents a serious property hazard may not pose a serious life hazard or vice versa.

Casualties, moreover, are not the only concern of the Fire Department. Fires cause a large amount of property loss and also result in a good deal of human suffering. Therefore, it is important for the Department to know how much effect it can have on casualty risks by reducing response distances so that it can appropriately balance its priorities.

Section II of this paper examines casualty incidence in New York City from 1967 to 1972 and its relation to temporal and demographic factors. Section III examines the relationship between casualty incidence and fire-company response distance.

II. FIRE CASUALTIES AND DEMOGRAPHIC FACTORS

In this section, we examine the relationship between fire casualties and factors such as time of day, occupancy type, and location of fires. There are several problems involved in defining and interpreting the relevant data. For example, while the total number of fatalities per season may be meaningful as an indicator of the cyclical variation of risk to life, the number of fatalities per hazard region has no meaningful interpretation as a measure of risk per region of the City because of the differing populations and areas of the regions.

There are further problems involved in trying to normalize the data by constructing "per fire" ratios. In the summer, for example, there are a large number of nonserious fires. A fatalities-per-fire index would therefore tend to indicate a smaller risk during this season even if the number of fatalities per season were constant throughout the year. But redefining the index to adjust for fire seriousness evades the point that the *average* fire is indeed less risky during the summer.

In spite of this difficulty, we have calculated both fatalities and injuries per structural fire for various periods of time, occupancies, etc. (In New York City, any fire within a structure, including "food on the stove," is classified as structural.)

Other difficulties appear in trying to define fatalities per capita. For instance, one cannot calculate this index by time of day without knowing how the population shifts over the day from residential to commercial occupancies. We have attempted to adjust for this shift in calculating casualties per capita by using estimates of daytime population.

These numbers may also tend to be misleading. If we knew that the number of fatalities per capita in first-floor occupancies was lower than that in sixth-floor occupancies, a first conclusion might be that the higher floor is more hazardous. However, the index might merely mean that private occupancies, which would be heavily represented in the first- and second-floor fires, are less hazardous than multiple dwellings.

Therefore, the indices presented should be taken only as a rough indicator of the risks associated with temporal and demographic factors. Further analysis is being carried out, at a much more detailed level, to find more significant relationships.

A final caveat to bear in mind when examining casualty indices is that casualties, particularly fatalites, are rare events. When an index is small, it is subject to substantial random variation. For this reason, the coefficient of variation, a measure of statistical deviation (explained in the Appendix), is presented along with the indices.

For example, there were .00575 fatalities per structural fire in 1967 and .00645 fatalities per structural fire in 1968 (see Table 1). But were the factors underlying fatalities in these years different? The coefficient of variation lets us estimate a range of values of the index for each year that might reasonably have been associated with the same underlying situation. Thus, a value of fatalities per structural fire in the range .00575 (1-2 x .093) to .00575 (1+2 x .093) or .00468 to .00682 might reasonably have resulted from the same underlying factors in 1967 (see the Appendix). Likewise, the index for 1968 might have ranged from .0547 to .0749. Since the ranges for 1967 and 1968 largely overlap, we can conclude that the differences between the observed indices are probably the result of random variation and not different underlying factors.

Data for fire fatalities for the years 1967 to 1972 were obtained from the fire fatality file [1]* created at the Institute. Data for injuries were obtained from files of information on individual alarms compiled by the New York City Fire Department. Injury data for 1967 were not available.

Table 1 shows the relationship between casualties and year. No secular change in casualties over 1967-1972 can be discerned.

Table 1

CASUALTIES vs. YEAR

	Fatalities (1967-1972)			Injuries (1968-1972)		
Year	Number	Fatalities per Structural Fire	Coefficient of Variation[a]	Number	Injuries per Structural Fire	Coefficient of Variation[a]
1967	231	.00575	.093			
1968	301	.00645	.081	1875	.04022	.032
1969	318	.00670	.079	2016	.04245	.031
1970	323	.00676	.078	1915	.04011	.032
1971	285	.00583	.083	2140	.04376	.030
1972	279	.00584	.084	1986	.04160	.031
All Years	1737	.00626		9932	.04169	

[a]See Appendix.

*Figures in square brackets denote references listed at the end of this document.

New York has been geographically divided into 21 areas called hazard regions. These regions are meant to be small enough to be relatively homogeneous and large enough to smooth out local variations. They were constructed by aggregating New York City Fire Department battalion boundaries in such a way that each hazard region contains fire hazards that are predominantly of a particular type. A map showing the locations of New York's 21 hazard regions is given in Fig. 1. Table 2 lists casualties per structural fire and per capita by hazard region. The most meaningful set of figures in this table is the casualties per capita. It appears, as expected, that casualty risks in Regions 2, 6, 9, and 12 (regions of high hazard) are significantly greater than those in Regions 8, 11, 13, 14, 15, and 21 (regions of low hazard). But the number of injuries per capita in Regions 10, 19, and 20 is surprisingly large since these regions are generally considered to be of low hazard.

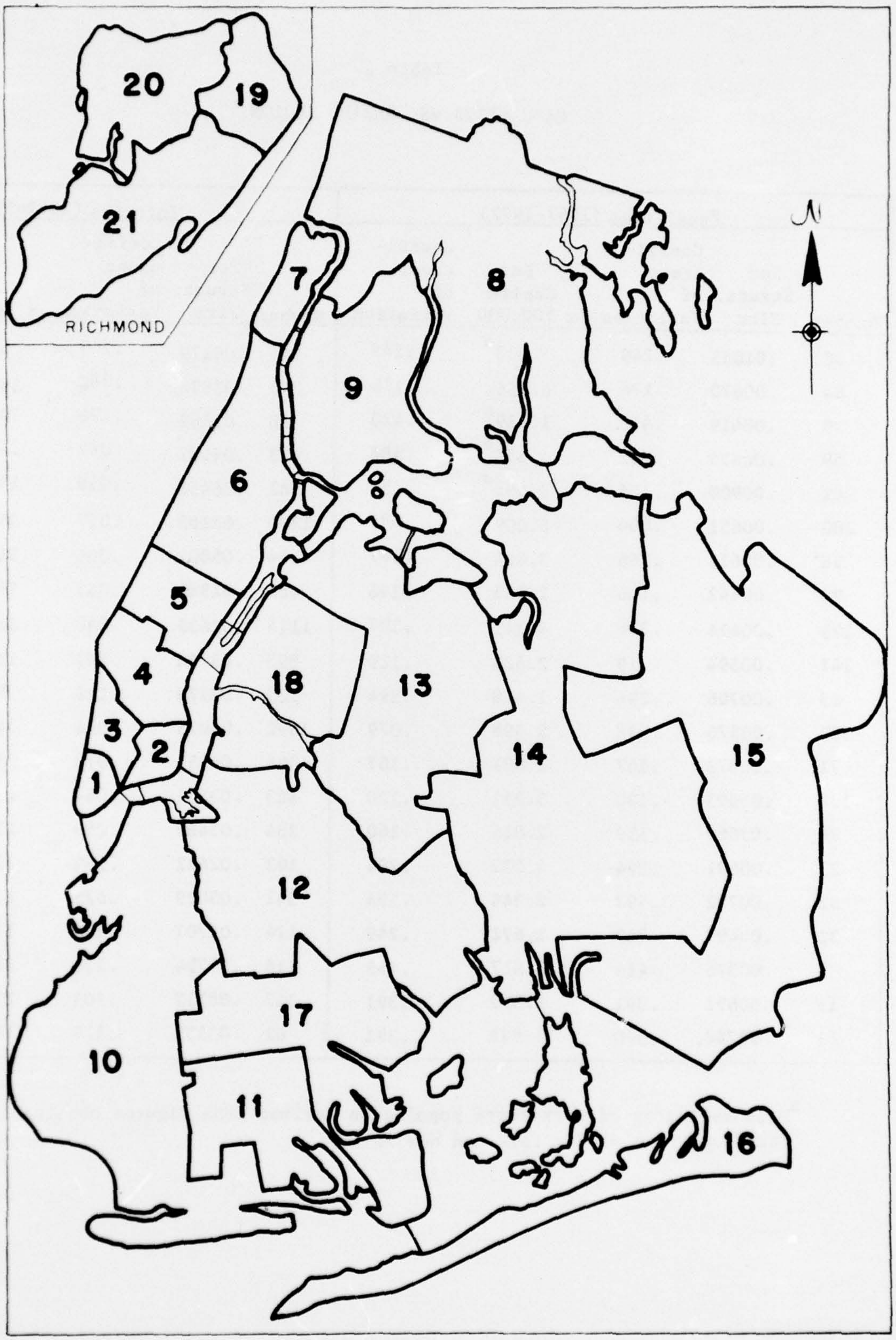

Figure 1. Hazard regions.

Table 2

CASUALTIES VS. HAZARD REGION

Hazard Region	Fatalities (1967-1972)					Injuries (1968-1972)				
	Number	Per Struct. Fire	Coefficient of Variation	Per Capita x 100,000	Coefficient of Variation	Number	Per Struct. Fire	Coefficient of Variation	Per Capita x 100,000	Coefficient of Variation
1	32	.01035	.249	.953[a]	.249	191	.06179	.100	6.826[a]	.102
2	64	.00670	.176	6.856	.176	275	.02878	.082	35.350	.085
3	9	.00419	.470	1.139[a]	.470	68	.03169	.170	10.334[a]	.171
4	59	.00625	.183	1.614[a]	.184	433	.04587	.067	14.220[a]	.068
5	81	.00900	.156	1.698[a]	.157	581	.06458	.058	14.616[a]	.058
6	280	.00651	.084	6.009	.084	1370	.03183	.037	35.278	.038
7	28	.00615	.266	3.064	.267	264	.05801	.085	34.370	.087
8	93	.00442	.146	2.035	.146	629	.02986	.056	16.516	.056
9	175	.00414	.106	4.141	.107	1114	.02635	.042	31.628	.042
10	141	.00594	.119	2.623	.119	893	.03764	.047	19.934	.047
11	23	.00706	.294	1.448	.294	123	.03773	.126	9.293	.127
12	322	.00576	.078	5.398	.079	1692	.03025	.034	34.037	.034
13	71	.00872	.167	2.031	.167	395	.04853	.070	13.561	.071
14	138	.01093	.120	3.211	.120	483	.03826	.064	13.484	.064
15	78	.01069	.159	2.816	.160	254	.03482	.088	11.005	.088
16	23	.00591	.294	4.001	.294	102	.02622	.139	21.295	.140
17	53	.00782	.193	2.344	.194	341	.05029	.075	18.098	.076
18	32	.00497	.249	2.672	.249	174	.02701	.106	17.435	.107
19	8	.00376	.484	1.817	.499	114	.04794	.130	31.068	.132
20	13	.00651	.391	1.550	.391	162	.08112	.109	23.183	.111
21	13	.00758	.390	2.633	.391	61	.03555	.179	14.825	.181

[a] Uses estimates of work-force population derived from figures obtained from the Port Authority of New York and New Jersey.

Tables 3 and 4 show the relationships between casualties and time of day and season, respectively. As expected, the greatest levels of casualties occur at night. However, fatalities peak between the hours

Table 3

CASUALTIES vs. TIME OF DAY

Time	Fatalities (1967-1972) Number[a]	Per Structural Fire	Coefficient of Variation	Injuries (1968-1972) Number	Per Structural Fire	Coefficient of Variation
2400-0359	372	.01100	.073	1690	.05000	.034
0400-0759	351	.01712	.075	1226	.05981	.040
0800-1159	215	.00627	.096	1542	.04497	.035
1200-1559	208	.00362	.098	1660	.02889	.034
1600-1959	222	.00304	.095	1864	.02557	.032
2000-2359	299	.00502	.081	1950	.03275	.032

[a] 70 missing values.

Table 4

CASUALTIES vs. SEASON

Season	Fatalities (1967-1972) Number	Per Structural Fire	Coefficient of Variation	Injuries (1968-1972) Number	Per Structural Fire	Coefficient of Variation
Dec. - Feb.	661	.00959	.055	3189	.04624	.024
Mar. - May	516	.00689	.062	2615	.03491	.027
June - Aug.	240	.00346	.091	1967	.02833	.031
Sept.- Nov.	320	.00493	.079	2161	.03330	.030

of 12 midnight and 8 a.m., while injuries peak between the hours of 4 p.m. and 12 midnight. Both fatalities and injuries reach their greatest levels during the winter months.

Table 5 lists casualties by building-construction type. These data are very hard to interpret because construction may be a proxy for many other demographic factors. But frame houses have the highest casualty rate.

Table 5

CASUALTIES vs. CONSTRUCTION

Type	Fatalities (1967-1972)			Injuries (1968-1972)		
	Number[a]	Per Structural Fire	Coefficient of Variation	Number	Per Structural Fire	Coefficient of Variation
Fireproof	137	.00318	.120	1362	.0316	.038
Frame	316	.00906	.079	1445	.0414	.037
Other	1060	.00528	.043	7125	.0355	.016

[a]224 missing values.

Table 6 shows casualties by floor. The index (casualties per structural fire) is the ratio of the number of casualties on a given floor to the number of fires originating on that floor. Since fires tend to spread upward, we would expect a relatively large number of fatalities on higher floors. This is seen in the data. However, since private dwellings are heavily represented in the lower-floor categories, and a large proportion of these dwellings are of frame construction, we might have expected a higher rate of casualties for the lower-floor categories too. Evidently, a more detailed examination of the casualty data is necessary to adequately explain this data.

Table 6

CASUALTIES vs. FLOOR

Floor	Fatalities (1967-1972)			Injuries (1968-1972)		
	Number[a]	Per Structural Fire	Coefficient of Variation	Number	Per Structural Fire	Coefficient of Variation
1st	462	.00503	.065	3050	.0332	.025
2nd	371	.00877	.073	1924	.0455	.032
3rd	245	.00855	.090	1272	.0444	.039
4th	146	.00720	.117	934	.0460	.046
5th	124	.00968	.126	597	.0466	.057
6th and Above	155	.00934	.113	929	.0560	.046
Below Ground	127	.00246	.125	1041	.0202	.043

[a]107 missing or not meaningful.

Table 7 shows the relationship between the most common occupancy types and fire casualties. As is the case with construction type, occupancy type may be a proxy for other demographic factors. But the results show that single room occupancies and private residences have relatively high casualty rates.

Table 7

CASUALTIES vs. OCCUPANCY

Type	Fatalities (1967-1972)			Injuries (1968-1972)		
	Number[a]	Per Structural Fire	Coefficient of Variation	Number	Per Structural Fire	Coefficient of Variation
Factory	12	.00132	.407	252	.0277	.088
Store	45	.00260	.210	494	.0286	.063
Garage	25	.00395	.282	255	.0403	.087
Warehouse	15	.00213	.364	251	.0357	.088
Apartment House	283	.00492	.084	1993	.0347	.031
Single Room	81	.01171	.156	468	.0677	.064
Private	340	.01146	.076	1536	.0518	.035
Tenements	558	.00620	.060	3880	.0402	.022
Other Residential	63	.00996	.177	282	.0446	.083
Public	22	.00184	.301	282	.0237	.083
Vacant	25	.00085	.282	206	.0070	.098

[a] 220 other or missing values.

The data presented above, although subject to the qualifications stated at the beginning of this section, clearly demonstrate that the risk of a fire casualty is by no means similar for different areas of the City, types of building construction, types of occupancy, seasons or times of day. Supplementary research, however, will be required to determine the operational significance of these results.

III. THE RELATION BETWEEN FIRE CASUALTIES AND RESPONSE DISTANCE

It is generally accepted that the longer a fire company takes to respond to a fire, the greater the chance of that fire becoming serious. Since it is likely that serious fires present a greater risk to life than nonserious ones, it would seem reasonable to infer that long travel times are associated with an above-average chance of a fire casualty. For the purpose of deploying fire-fighting resources, however, it is important to know how strong the relationship is between travel times and fire casualties.

This question is not easy to answer because there are many factors other than travel time--such as delay in turning in an alarm, location, time of day, etc.--that may contribute to the chance of a casualty. Furthermore, even if a fire is serious, the occurrence of a casualty, especially of a fatality, is an unlikely and random event depending on many factors difficult or impossible to assess. We would expect, therefore, that a straightforward comparison of fatality and injury incidence to travel times would prove inconclusive.

We have therefore attempted to make a comparison of fatal and nonfatal fires and of injurious and noninjurious fires in such a way that factors such as the time of day or the location of the fire do not influence the results. In making this comparison, we have used response distance as a proxy for travel time since distances may be estimated directly from available data.

The fire fatality file [1] for the years 1969 to 1971 was used as the source of data for fatalities. A file consisting of all structural fires for which an injury but not a fatality was recorded was also constructed for these years. Since some of these injuries might have become fatalities 24 hours or more after the fire, this file was compared with the fatality file to eliminate duplications. In the following, the methodology for judging the strength of the fatality-response distance relationship is discussed. The methodology for injuries and response distance is identical.

In order to compare fatal and nonfatal fires with similar attributes, a pairing scheme was used. For every fatal fire we attempted to find a nonfatal fire with the following matching attributes:

Same time period of day: 0000-0359, 0400-0759, 0800-1159, 1200-1559, 1600-1959, or 2000-2359.

Same season: Dec. - Feb., Mar. - May, June - Aug., or Sept. - Nov.

<u>Same cause category</u>: arson-explosions, careless cooking, or other.

<u>Same construction type</u>: fireproof, frame, or other.

<u>Same occupancy type</u>: multiple dwelling "A," multiple dwelling "B," private dwelling, commercial, vacant, or public.

<u>Same battalion</u>.

<u>Same method of reporting</u>: box or phone.

If there were more than one nonfatal matching fire, the tie was broken by picking a fire on the same floor. If there were still duplicate matches, the tie was broken by matching according to room of origin (kitchen, bedroom, living room, vacant area, area outside building, basement, storage room, work area, bathroom, or other). Any remaining ties were resolved by using a random selection of the matching nonfatal fire. Table 8 shows how many matches were successfully obtained.

Table 8

MATCHING STATISTICS

	Fires With Fatalities	Fires With Injuries
No Match Obtained	96	488
Matched on Seven Attributes Only	128	758
Also Matched on Floor	136	800
Also Matched on Floor and Room	205	1412
Total Cases	565	3458

The estimated response distance d_1 of the first-arriving engine and the response distance d_2 of the first-arriving ladder were added to the record of each fire, as documented in [2]. When, in certain cases, it was not possible to estimate this distance, the pair was excluded from the appropriate calculations. For each pair, the following set of variables was calculated:

$$V_i = d_{if} - d_{in} \quad (i=1 \text{ or } 2),$$

where d_{if} = distance type i for the fatal or injurious fire

d_{in} = distance type i for the nonfatal or noninjurious fire.

The variable V_1 for a given pair of fires would be positive if the engine response distance to the fatal fire were greater than the response distance to the nonfatal fire. If response distance significantly alters the chance of a fire being fatal, we would expect to find the average value $\overline{V}$ to be positive and significantly different from zero.

For a given nonzero value of $\overline{V}$, estimated from a sample, the lower the variance of the sample, the more confidence we may have that the true value of $\overline{V}$ is nonzero. The pairing scheme described above tends to lower the sample variance.

The results for the fatality pairing are given in Table 9.

Table 9

FATALITY-NONFATALITY PAIRS

	Engine Distance Difference (miles)	Ladder Distance Difference (miles)
Average = $\overline{V}$	.004	.006
Standard Deviation of $\overline{V}$	.0167	.0215
Standard Deviation of V	.352	.454
Number of Cases	442	445

Table 10 lists similar data for fires at which an injury occurred.

Table 10

INJURY-NONINJURY PAIRS

	Engine Distance Difference (miles)	Ladder Distance Difference (miles)
Average = $\overline{V}$	.008	.012
Standard Deviation of $\overline{V}$	.0070	.0084
Standard Deviation of V	.370	.446
Number of Cases	2735	2736

For both injuries and fatalities, the average differences in response distance are of the order of hundredths of a mile (fifty feet) while the standard deviations are of the order of a third of a mile. This means that a relation between casualties and response distance, if present, is rather small compared with other factors. None of the means of the differences of response distancc for fatal pairs is significantly different from zero. For injury data, however, the mean of the engine-distance difference is significantly nonzero at the 87 percent level, and for ladders it is significantly nonzero at the 92 percent level.

An additional set of runs was made exclusively for casualty pairs that matched on all nine attributes. The results are shown in Table 11 and Table 12.

Table 11

FATAL-NONFATAL PAIRS
MATCHING ON FLOOR AND ROOM

	Engine Distance Difference (miles)	Ladder Distance Difference (miles)
Average = $\bar{V}$	.019	.041
Standard Deviation of $\bar{V}$	.028	.036
Standard Deviation of V	.382	.500
Number of Cases	191	191

Table 12

INJURY-NONINJURY PAIRS
MATCHING ON FLOOR AND ROOM

	Engine Distance Difference (miles)	Ladder Distance Difference (miles)
Average = $\bar{V}$	.017	.009
Standard Deviation of $\bar{V}$	.010	.013
Standard Deviation of V	.372	.451
Number of Cases	1258	1255

For this run of pairs, which were selected under more stringent conditions, we find that the difference in ladder distances for fatal vs. nonfatal fires is significantly nonzero at the 87 percent level.

It is to be expected, simply on the basis of physical considerations, that the risk of a casualty will be larger at fires further away from the closest responding fire companies. The levels of statistical confidence attained in this study indicate that sufficient data were used in an appropriate manner to discern this relation. The significant conclusion of this study, however, is that the effect of fire company response distance (for average distances typical of New York City) on fire casualties is very small compared to the effects of other factors.

IV. CONCLUSIONS

While a statistically significant relation exists between response distance and fire casualties, this relationship is overwhelmed by many other factors. Therefore, risk to life cannot be used as the primary criterion in developing mathematical fire-resource allocation models. It is also apparent that a much more detailed study of individual casualty incidents will be necessary for a better understanding of their causes and of how they may be prevented.

Appendix

ESTIMATES OF THE COEFFICIENT OF VARIATION

Let r be the expected number of casualties per structural fire or per population for a given class of fire. Then each of the indices presented in Section II of this Note is a statistical estimate of r. The estimation is made by calculating $\hat{r} = f/N$, where f is the number of casualties in a class and N is the number of fires or the population in that class.

In order to assess the confidence one should have in this estimate, a measure of statistical deviation is also presented. We use an estimate of the coefficient of variation defined as follows:

$$\text{coefficient of variation} = \hat{\sigma}/\hat{r},$$

where $\hat{\sigma}$ is an estimate of the sample standard deviation of $\hat{r}$. A coefficient of variation of .1 would mean, roughly, that the standard deviation is one-tenth the size of the expected value, so that there would be a better-than-90 percent chance, say, that the true expected value is in the range $\hat{r} \pm 15\% \, \hat{r}$ [3]. A coefficient of .2 would double that range to $\pm$ 30 percent and so on.

We calculate $\hat{\sigma}$ by assuming that a fire casualty is the result of a compound random event consisting of two independent simple events. One is the occurrence of a fatal fire, the other is the occurrence of a given number of fatalities at that fire. For a given class of fire, let

X_i = 1 if the ith fire is fatal
= 0 otherwise
Y_i = the number of fatalities at the ith fire given i is fatal.

If we let R_i be the number of fatalities at fire i, then $R_i = 0$ if $X_i = 0$, so we can write $R_i = X_i Y_i$. We then have $r = E(R_i) = E(X_i Y_i)$ and $\hat{r} = (R_1 + \ldots + R_N)/N$.

Dropping the subscripts, if the two events are independent:

$$r = E(X)\, E(Y) = p\, E(Y),$$

where p = E(X), the probability that a fire is fatal.

We calculate the variance of R as follows:

$$\begin{aligned} \mathrm{Var}\ (R) &= E(R^2) - E^2(R) \\ &= E(X^2Y^2) - p^2E^2(Y) \\ &= p\ E(Y^2) - p^2E^2(Y). \end{aligned}$$

The variance of $\hat{r}$ is given by $\sigma^2 = \frac{\mathrm{Var}(R)}{N}$, which may be written:

$$\sigma^2 = \frac{p\ E(Y)}{N}\left(\frac{E(Y^2)}{E(Y)} - p\ E(Y)\right)$$

$$= \frac{r}{N}\left(\frac{E(Y^2)}{E(Y)} - r\right).$$

We estimate the variance by replacing r with $\hat{r}$ and replacing $E(Y^2)/E(Y)$ for a given class of fire by the estimate $\alpha = \Sigma_i Y_i^2/\Sigma_i Y_i$, where the sum is over all fatal fires. Thus,

$$\hat{\sigma}^2 = \frac{\hat{r}}{N}(\alpha - \hat{r})$$

and

$$\frac{\hat{\sigma}}{\hat{r}} = \sqrt{\frac{\alpha - \hat{f}}{\hat{f}N}} = \sqrt{\frac{\alpha - \hat{f}}{f}}\ .$$

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